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DESIGN PROBLEMS IN VISUAL DISPLAYS
Part II. Factors in the Legibility of Televised Displays

SEPTEMBER 1966

D. A. Shurtleff

Prepared for
DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

ESRH

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Project 7030
Prepared by
THE MITRE CORPORATION
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FOREWORD

This report is one of a series discussing design problems in visual displays. Additional information on this topic may be found in the following report: "Design Problems in Visual Displays, Part I. Classical Factors in the Legibility of Numerals and Capital Letters," by D. Shurtleff, The MITRE Corporation, Bedford, Massachusetts, ESD-TR-66-62, June 1966.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the reports findings or conclusions. It is published only for the exchange and stimulation of ideas.

James D. Baker

JAMES D. BAKER
703 Project Officer
Decision Sciences Laboratory

Roy Morgan

ROY MORGAN
Colonel, USAF
Director, Decision Sciences Laboratory

ABSTRACT

The literature on the legibility of numerals, capital letters, and words on television displays, dating from the late 1940s to the present, is evaluated. Selected studies of such factors as vertical resolution, video bandwidth, and direction of scanning are reviewed in detail. Conclusions are drawn, and recommendations are made for display design and applications.

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GLOSSARY

Accuracy of Identification. The number of correct symbol identifications divided by the total number of symbol identifications times 100.

Active Line. The light line of a raster formed by the scanning element.

Ambient Illumination. The light incident upon the display and surrounding areas. The light density in these areas is typically measured in foot candles.

Brightness. A photometric term describing a human judgment of the intensity of a light source. There are many units in which the brightness is measured, but they may be divided into two classes: (a) luminance, which is measured in candles per unit area (mm, cm, etc.) and (b) luminance emittance, which is measured in lambert units or any combination of lambert units. For a detailed discussion of brightness and other photometric terms, see reference 1, page 53.

Brightness Contrast: A measure of the relative difference between the brightness of a symbol and the brightness of the symbol's background. There are several different equations for determining brightness contrast. The one used in this paper was suggested by R. T. Mitchell. It is: brightness contrast equals the brightness of the symbol minus the brightness of the background all divided by the brighter of the two. Brightness contrast can vary from minus 1.00 to plus 1.00. Negative values of contrast indicate that the symbol is darker than the the background, and positive values of contrast indicate that the symbol is lighter than the background.

Confusion Matrix. A table showing the number of times each of "n" symbols is presented and the frequency with which a symbol is identified either correctly or as any one of the "n-1" other symbols. The matrix is useful for such things as indicating particular symbol pairs which are commonly confused, particular

symbols which are generally confused with many other symbols, identification preferences of the subjects, etc.

Field. For the purposes of this report, a field is one vertical sweep of the scanning element yielding a raster with approximately one-half of the rated number of lines (525 or 945) and requiring 1/60 second.

525-Line. A raster composed of 525 active lines. Approximately 80 percent of these lines appear in the raster on the monitor.

Frame. For the purpose of this report, a frame is two successive fields requiring 1/30 second.

Foot-Candle (ft-c). The illumination falling on a surface which is located at a distance of one foot from a point source of one international candle.

Foot-Lambert (ft-l). A measure of luminous emittance (see brightness).

Identification Speed. Refer to speed of identification.

Horizontal Spacing. A measure of the distance between vertical tangents erected at the outer limits of adjacent symbols.

Inactive Line. The dark line of a raster between two adjacent active lines.

Interlace. The active lines of alternate fields of a frame that may overlap each other, that is, occur one on top of the other, or the lines of one field may occur between the lines of the preceding or following field. (See also random interlace, synced interlace, two-to-one interlace, and interlace quality.)

Interlace Quality. The ratio of the distance between the centers of adjacent active lines of two successive fields to the distance between the centers of the second of these lines and the next adjacent active line (all distances are expressed as percentages of the sum of the two distances); the first and third active lines thus belong to the same field. When the active lines of successive fields are equidistant, the interlace quality is 50/50.

Legible. Traditionally, capable of being read or deciphered, and was used to refer to both text and single symbols. It has no standard meaning. It is used by some investigators to refer to a property of letters and numerals, and by other investigators to refer to a property of text. In this report legibility refers to a property of letters and numerals which is measured in objective performance units of identification accuracy, rate, speed, and threshold.

945-Line. A raster composed of 945 active lines. Approximately 80 percent of these lines appear in the raster on the monitor.

Normal Line of Sight. The line connecting the fovea to the point of fixation (visual axis) perpendicular to the display surface. In practice, the two eyes are regarded as coincident, in which case the normal line of sight is considered as a single, straight line. The studies reported in this report refer to the 90 degree viewing angle when the visual axis is perpendicular to the display surface; to other investigators, however, this represents a zero degree viewing angle.

Random Interlace. The interlace quality may vary from frame to frame.

Raster. The pattern of alternating dark and light lines formed by the scanning element.

Speed of Identification or Identification Speed. The rapidity with which a symbol is identified by the subject. In experimental psychology, it is a measure of reaction time and is the interval between the presentation of a stimulus (symbol) and the subject's response (identification). Estimates of identification speed are often unknowingly biased by the measurement technique. If care is not taken to eliminate from speed scores artifacts arising from apparatus delays in symbol presentation and response recording, then speed scores will not mean the same thing in different studies.

Symbol Set. The 26 letters of the alphabet; the 10 numerals; or all alphanumerics, consisting of the 26 letters of the alphabet and the 10 numerals.

Synced Interlace. The horizontal and vertical oscillators are synchronized to provide constant, or nearly constant, interlace quality from frame to frame.

Tachistoscope. An experimental device for controlling the exposure of stimulus material, e.g., symbols.

Two-to-one Interlace. The interlace of two fields in one frame.

Video Bandwidth. The frequency at which the voltage gain in a video amplifier is some specified fraction of the gain at a lower frequency; one convention uses the fraction 0.707 of the gain at the mid-frequency point.

Visual Acuity. The ability of the eye to distinguish fine detail. Near acuity is a measure of resolving power of the eye at a distance of approximately 1 foot. Far acuity is a measure of the resolving power of the eye at a distance of approximately 20 feet. In experimental studies, acuity is commonly reported as the reciprocal of the smallest detail, measured in minutes of arc, which the eye is capable of resolving.

In the Snellen test at a rating of 20/20, the subject is said to be able to resolve detail subtending 1 minute of arc at the eye. However, other tests of acuity indicate that the eye is capable of resolving much finer detail. For example, under ideal conditions, the eye is capable of resolving a length of wire across a bright field when the width of the wire subtends approximately 0.5 second of visual angle.

Visual Angle. The angle subtended at the eye by a visual object. For example, the visual angle, $0 = 2 \tan_{x}$, where $x = h/2d$, h = the height of the symbol and d = the distance from the symbol to the eye of the subject.

SECTION I

INTRODUCTION

This report is the second in a planned series of reports on selected problems in the design of visual displays. The first report summarized the literature on classical factors in the legibility of capital letters and numerals. The present report reviews the legibility of televised capital letters, numerals, and words.

These reviews include

(a) a brief summary of experimental studies on the effects on legibility of selected display properties,

(b) a critical interpretation of the findings of these studies, and

(c) recommendations about the values of display properties to use in operational situations.

The major purpose of these reviews is to provide the manufacturer, procurer, and user of visual displays with design guides to assist them in the better selection of display properties. As pointed out earlier, [2] these reviews are consider only as guides to the selection of display properties. The final evaluation of display design is a test (or tests) which show the operator can identify the display symbols with an accuracy and speed required by the task to be performed. Appropriate tests of operator performance were outlined in a previous report[3].

SECTION II

TELEVISION RESEARCH LITERATURE

A search of the television literature began 4 years ago. Studies published from the late 1940s to the present were reviewed. Some 100 documents were read, but only 16 were found satisfactory for detailed consideration. A document was considered satisfactory for the present review if it dealt with the legibility of capital letters, numerals, or words and used a procedure in which the viewer identified televised symbols or words rather than mode judgments about legibility. The criteria for selecting studies are discussed in the following paragraphs.

The literature search uncovered three areas which are the main producers of documents on television; commercial (broadcast) television, visual-aid television, and military electronic systems television.

Research in broadcast television is concerned mainly with the evaluation of picture quality and very little is done on the legibility of television displays. Studies in the area of broadcast television investigated such things as the perceptibility of power-line interference[4], the optimum surround brightness for home viewing of television[5], the amount of flicker of phosphors and powerline frequencies[6]. Furthermore the procedures used to evaluate broadcast television often required the viewer to give his opinion or judgment about the degree of impairment of picture quality caused by the factor of interest. While such procedures are suitable for evaluation of broadcast television, they are not suitable for system design because of failure to yield numbers relating to the viewer's ability to identify symbols or read words. Consequently, most of the documents in the area of broadcast television are not satisfactory

for the present review because of the nature of the properties investigated and the procedure used in the investigation.

In the area of visual-aid television, there are some investigations of legibility, but they represent a small part of the total research effort in this area. Most of the research is concerned with a comparison between television and some other visual aid[7], or with the use of television in situations not directly observable by students. Also, the viewer's judgments or opinions are frequently used to evaluate television displays. Again, the broadcast television area, most of the documents on visual-aid television are not satisfactory for the same reason.

In contrast to the areas previously discussed, a major emphasis of military systems television research is display legibility. The reason is a common task requirement of the operators in military systems for rapid and accurate identification of alphanumeric symbols and words. The design of military systems must provide display properties to enable the operator to identify symbols rapidly and with minimal error. To ensure operator performance, design guides must establish how performance is affected by such factors as vertical symbol resolution (the number of vertical scan lines per symbol height), the angle of scanning, the video bandwidth of television systems, and various other factors. It is not surprising, therefore, considering the requirements of military systems, that most of the documents reviewed in this paper are from military applications of television. Not all the documents from this area are satisfactory even though they deal with the legibility of television displays. Studies using viewers' opinions or judgments about legibility are usually not reviewed and preference is given instead to studies which show the viewer's ability to identify televised symbols and words.

Finally, preference is given to studies in which the subjects were visually screened. Data collected on "uncalibrated" subjects was not likely to be very reliable. A study is also most useful if it reported in detail the conditions of the experiment. Therefore, a description of the experimental conditions is given for each of the studies reviewed.

Only 1 out of 10 documents on television satisfied these criteria. The following sections report on the various properties of television displays and their affects on the viewers' accuracy, rate, speed, and threshold of identification (visual size required for a given accuracy of identification). A glossary of technical words is included after the table of contents.

SECTION III

SUMMARY OF THE LEGIBILITY OF TELEVISED SYMBOLS

VERTICAL RESOLUTION

The major emphasis of the work on television is the effects on legibility of different values of symbol resolution; that is, on determining the minimum number of lines per symbol height required for good legibility.

Accuracy of Identification

Botha and Shurtleff[8] compared two idealized television line constructions of 5 and 11 lines per symbol height. Television symbols were simulated by use of photographic grids made up of alternate transparent and opaque lines. The grids were superimposed on superimposed on solid-stroke Futura capital letters (Figure 1) and were shown one at a time to subjects by means of a tachistoscope. The symbols were shown at exposure times of 0.03 and 0.003 second and with stroke-widths of 17 and 28 percent of symbol height. The results of the study, shown in Table I, indicated a high accuracy of identification for both the solid-stroke symbols and the 11 line constructions for an exposure time of 0.03 second. For a resolution of 5 lines, at 0.03 second, accuracy decreased for both stroke-widths but with a greater decrease for the narrower stroke-width. At an exposure of 0.003 second, accuracy of identification was reduced for both symbol resolutions over that found for an exposure of 0.03 second while accuracy for the solid-stroke symbols was not affected by a similar reduction in exposure time.

In a study by Shurtleff and Owen[9] live television was used to evaluate symbol resolutions of 12, 10, 8, and 6 lines per symbol height. Leroy and Courtney symbols (Figure 2) were shown one at a time on a Miratel, 14-inch, video monitor connected to a 525-line, Fairchild television camera

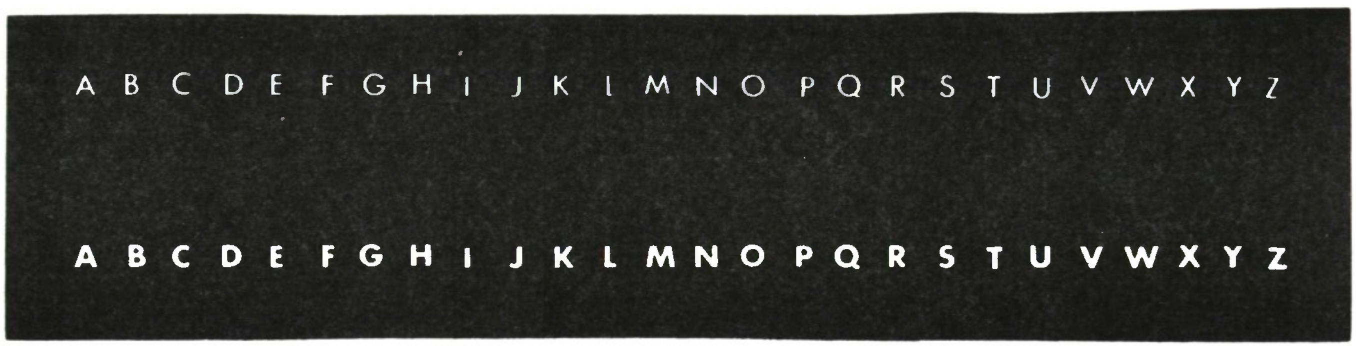

Figure 1. Letters Used by Shurtleff, Botha and Young and by Seibert, Kasten, and Potter. The Futura Medium letters are at the top and the Futura Bold letters are at the bottom. (After Shurtleff, Botha, and Young, 1964.)

TABLE I

Accuracy of Identification, in percentage correct for two values of exposure time, two values of stroke-width, two values of symbol resolution, and for solid-stroke symbols. (After Botha and Shurtleff, 1962.)

Exposure Time	Stroke-Width	Lines Per Symbol Height		
		Solid	11	5
0.03	16	99	98	88
	28	98	98	93
0.003	16	98	72	71
	28	98	83	81

Description of Experimental Conditions:

Symbol Brightness: 28 ft-l

Background Brightness: 1.5 ft-l

Brightness Contrast: + 0.96

Ambient Illumination: Not stated

Symbol-Background Relation: L/D

Symbol Style: Futura Bold and Medium (see Figure 1)

Horizontal Spacing: Not relevant

Symbol Width: 77 to 87 percent of symbol height

Visual Size: 14 minutes of arc

Number of Symbols: 26 Letters

Number of Subjects: 4

Visual Characteristics of Subjects: 20/20 near and far acuity; normal color

Viewing Distance: 31 inches

Viewing Angle: 90 degrees

Figure 2. Alphanumerics Used by Shurtleff and Owen. The Leroy symbols are at the top and the Courtney symbols are at the bottom. (After Shurtleff and Owen, 1966.)

(Model TC-100). The camera-to-symbol distance was arranged to obtain the values of symbol resolution and the subject-to-monitor distance was varied to maintain a common visual size of 11 minutes of arc. The results of the study are shown in Table II. Part I of the table describes the results obtained when the subjects had a minimum amount of practice and Part II when they had more extensive practice. The table shows that a progressive loss in accuracy of identification occurred for Part I as resolution decreased from 12 to 6 lines per symbol height. For Part II, accuracy is similar for symbol resolutions of 12 and 10 lines, but a decrease in accuracy occurs for resolutions of 8 and 6 lines per symbol height.

Elias, Snadowsky, and Rizy[10] determined the accuracy of identification for 9 values of symbol resolution from 3 to 11 lines per symbol height. Copperplate Gothic symbols (Figure 3) were shown one at a time to subjects on a General Precision (GPL) high-resolution television system. The television system included a PN 5358-6 Vidicon camera with a vertical resolution of 875 horizontal scan lines. The monitor was a 21-inch Conrac Model CQC operating on a 20-mc bandwidth. According to Elias, "For this experiment, complete line pairing was induced by permitting crosstalk between vertical and horizontal scan. This reduced the number of horizontal scan lines to approximately 437, but resulted in equal-width active and equal-width inactive elements."

Subjects were assigned to one of two groups; one group identified symbols with decreasing resolutions of 11 to 3 lines while 11 lines. The results of the study are in Table III. The main point of interest is that the major reduction in identification accuracy occurred when symbol resolution was reduced from 5 lines to 4 lines per symbol height. Accuracy is more or less uniform for symbol resolutions from 5 to 11 lines per symbol height.

TABLE II

Accuracy of Identification, in percentage correct, for two symbol fonts at four values of vertical symbol resolution. Part I represents accuracy obtained with a minimum amount of practice. Part II represents accuracy obtained with extensive practice. (After Shurtleff and Owen, 1966.)

	Symbol Style	Lines Per Symbol Height			
		12	10	8	6
Part I	Courtney	96.6	94.8	89.3	74.8
	Leroy	97.2	96.5	91.4	77.5
Part II	Courtney	96.8	97.0	92.0	91.0
	Leroy	96.1	96.3	93.6	83.8

<u>Description of Experimental Conditions:</u>

Symbol Brightness: 20 ft-l

Background Brightness: 1.5 ft-l

Brightness Contrast: +0.90

Ambient Illumination: Not stated

Symbol-Background Relation: L/D

Horizontal Spacing: Not relevant

Symbol Width: 75 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol height

Visual Size: 11 minutes of arc

Symbol Exposure Time: Variable

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 8

Visual Characteristics of Subjects: 20/20 near and far acuity; normal phoria and color

Viewing Distance: 36 to 64 inches

Viewing Angle: 90 degrees

A B C D E F G H I

J K L M N O P Q R

S T U V W X Y Z 1

2 3 4 5 6 7 8 9 Ø

Figure 3. Alphanumerics used by Elias, Snadowsky, and Rizy. (After Elias, Snadowsky, and Rizy, 1964.)

Table III

Accuracy of Identification, in percentage correct for nine values of vertical symbol resolution. (After Elias, Snadowsky, and Rizy, 1964.)

	Lines Per Symbol Height								
	11	10	9	8	7	6	5	4	3
Group I	99.5	99.2	99.8	99.3	99.5	99.1	98.8	87.4	43.1
Group II	99.8	99.5	99.4	98.6	98.1	97.3	92.6	50.0	20.2

Description of Experimental Conditions:

Symbol Brightness: 70 ft-l

Background Brightness: 1.0 ft-l

Brightness Contrast: +0.86

Ambient Illumination: Darkened room; only source of light - video monitor

Symbol-Background Relation: L/D

Symbol Style: Copperplate Gothic (see Figure 3)

Horizontal Spacing: Not relevant

Symbol Width: 100 percent*

Symbol Stroke-Width: 17 percent of symbol height

Visual Size: 24 minutes of arc

Symbol Exposure Time: 4 seconds

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 10

Visual Characteristics of Subjects: 20/20 near and far acuity; dark adapted for 5 minutes

Viewing Distance: Variable

Viewing Angle: 90 degress

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* Estimated by present author.

Conclusions and Recommendations

Two of the three studies indicate that the minimal acceptable vertical symbol resolution is 10 lines per symbol height. This finding is confirmed by the use of both idealized television symbol construction and live television constructions. The simulated study shows that, even with idealized television scan lines, resolutions less than 10 lines per symbol height leads to some loss in accuracy. On the other hand, the study of live television shows very little increase in accuracy for resolutions greater than 10 lines per symbol height.

The findings of the third study seem to conflict with those of the first and second studies in that accuracy did not deteriorate appreciably until symbol resolution was decreased below 5 or 6 lines per symbol height. This apparent conflict may result from differences in the quality of interlace used in these studies which lead to associated differences in the definition of a scan line. In the Shurtleff and Owen [9] study, a standard 2:1 interlace was used for the scan lines making up the first and second fields of a television frame. In the 2:1 interlace method, the lines of the second field fall midway between the lines of the first field. All lines, whether of the first or second fields, were counted in determining the values of symbol resolution. In the Elias [10] et al. Study, the lines making up the second field did not fall midway between those of the first field or superimposed to some degree on the lines of the first field. Thus, in either case, the lines of the two fields were visually indistinguishable and therefore possibly counted as a single line rather than as two superimposed or adjacent lines. It appears then that, with respect to the number of scan lines actually used, the 5 lines in the Elias study compare to the 10 lines in the Shurtleff study and the difference between the two is in the quality of the interlace of the lines of the first and second fields. If this analysis is correct, it indicates that the quality of the interlace is probably not a major factor in

accuracy of identification since performance at 5 lines in the Elias study is approximately the same as performance at 10 lines in the Shurtleff study.

Rate and Speed of Symbol Identification

The study by Botha and Shurtleff, shows speed of identification for solid-stroke symbols and idealized television constructions of 11 and 5 lines per symbol height. The results of the study are in Table IV. For a symbol exposure of 0.03 second, identification speeds are much the same for solid-stroke symbols and for symbol resolutions of 11 and 5 lines. For a symbol exposure time of 0.003 second, identification speeds for both symbol resolutions of 11 and 5 lines are significantly slower than that for solid-stroke symbols. There are no differences in identification speed between a symbol resolution of 11 lines and a symbol resolution of 5 lines.

Shurtleff and Owen [9] report identification speed for symbol resolutions of 12, 10, 8, and 6 lines when the symbols are displayed on a 525-line television monitor. The results, shown in Table V, indicate that speed of identification decreased progressively as symbol resolution decreased from 12 to 6 lines per symbol height. There is some improvement in identification speed with practice for all resolutions (compare Part I with Part II).

Elias [11] determined speed of identification for seven values of symbol resolution from 5 to 11 lines per symbol height and for nontelevised, solid-stroke symbols. The details of the experiment are the same as those reported on page 9 and in Table III. The results of the study, shown in Table VI, indicate a systematic decrease in speed of identification as vertical resolution decreased from 11 to 5 lines per symbol height. Identification time for nontelevised, solid-stroke symbols of the same visual size as the televised symbols was faster than for any television resolution studied.

Table IV

Speed of Identification, in seconds for two values of exposure time, two values of stroke-width, two values of vertical symbol resolution, and for solid-stroke symbols. (After Botha and Shurtleff, 1963.)

Exposure Time	Stroke-Width	Lines Per Symbol Height		
		Solid	11	5
0.03	16	0.44	0.45	0.46
	28	0.44	0.45	0.46
0.003	16	0.44	0.54	0.54
	28	0.42	0.48	0.49

Description of Experimental Conditions:

Symbol Brightness: 28 ft-l

Background Brightness: 1.5 ft-l

Brightness Contrast: +0.96

Ambient Illumination: Not stated

Symbol-Background Relation: L/D

Symbol Style: Future Bold and Medium (see Figure 1)

Horizontal Spacing: Not relevant

Symbol Width: 77 to 87 percent of symbol height

Visual Size: 14 minutes of arc

Number of Symbols: 26 Letters

Number of Subjects: 4

Visual Characteristics of Subjects: 20/20 near and far acuity; normal color

Viewing Distance: 31 inches

Viewing Angle: 90 degrees

Table V

Speed of Identification, in seconds for two symbol fonts at four values of vertical symbol resolution. Part I represents speed of identification obtained with a minimum amount of practice. Part II represents speed obtained with more extensive practice. (After Shurtleff and Owen, 1966.)

	Symbol Style	Lines Per Symbol Height			
		12	10	8	6
Part I	Courtney	0.57	0.66	1.06	1.22
	Leroy	0.49	0.54	0.70	1.08
Part II	Courtney	0.53	0.56	0.69	1.04
	Leroy	0.51	0.50	0.65	0.74

Description of Experimental Conditions:

Symbol Brightness: 20 ft-l

Background Brightness: 1.5 ft-l

Brightness Contrast: +0.90

Ambient Illumination: Not stated

Symbol-Background Relation: L/D

Horizontal Spacing: Not relevant

Symbol Width: 75 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol height

Visual Size: 11 minutes of arc

Symbol Exposure Time: Variable

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 8

Visual Characteristics of Subjects: 20/20 near and far acuity; normal phoria and color

Viewing Distance: 36 to 64 inches

Viewing Angle: 90 degrees

Table VI

Speed of Identification, in seconds for seven values of vertical symbol resolution and for nontelevised solid-stroke symbols. (After Elias, Snadowsky, and Rizy, 1964.)

	Lines Per Symbol Height							
	Solid	11	10	9	8	7	6	5
Average Response Time in Sec. *	0.58	0.61	0.62	0.64	0.66	0.67	0.69	0.79

Description of Experimental Conditions:

Symbol Brightness: 7.0 ft-l

Background Brightness: 1.0 ft-l

Brightness Contrast: +0.86

Ambient Illumination: Darkened room; only source of light - video monitor

Symbol-Background Relation: L/D

Symbol Style: Copperplate Gothic (see Figure 3)

Horizontal Spacing: Not relevant

Symbol Width: 100 percent**

Symbol Stroke-Width: 17 percent of symbol height

Visual Size: 24 minutes of arc

Symbol Exposure Time: 4 seconds

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 10

Visual Characteristics of Subjects: 20/20 near and far acuity; dark adapted for 5 minutes

Viewing Distance: Variable

Viewing Angle: 90 degrees

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* These values are only approximate since they were estimated from a graphic representation of the original data.

** Estimated by author of this report.

Conclusions and Recommendations

The study of idealized television symbols fails to show a difference in speed of identification between resolutions of 11 and 5 lines per symbol height. Both studies using live television, however, show a progressive decrease in speed of identification for each decrease in resolution. Therefore, identification speed scores for idealized television constructions are poor predictors of identification speed scores for similar constructions on live television.

The two studies of live television, while showing a decrease in identification speed with decreases in resolution, differ in the particular values of identification speed reported for comparable values of symbol resolution (compare scores for Leroy symbols at 10 and 8 lines with those for Copperplate Gothic at 10 and 8 lines). There are two problems standing in the way of any attempt to reconsile the two sets of data. The first problem, namely, differences in the quality of the interlace used in the two studies, was discussed in detail on page 13, and it was concluded that the comparison of results of the two studies should probably be 10 and 12 lines of the Shurtleff and Owen study with 6 and 5 lines of the Elias study. If this comparison is made, the differences in the reported identification speed scores are even greater than first thought (compare Leroy resolutions of 12 and 10 lines with Copperplate Gothic at 6 and 5 lines). The second problem is that there is no way of determining in the Elias study which part, if any, of identification speed was caused by delays in the equipment (e.g., response time of the relays and circuitry, rise time of the light source, maximum possible delay in completing one complete frame of the television raster, etc.). The delay times caused by the television equipment and associated apparatus was eliminated from speed of identification reported in the Shurtleff and Owen study. Therefore, part of the difference in identification times reported in the two studies may be that the scores of the Shurtleff and Owen study were corrected to account for equipment delays while those of

the Elias study were not similarly corrected. A second possibility is that the differences (or some part of them) in speed of identification may be caused by differences in the quality of interlace used in the two studies. While differences in the quality of interlace did not appear to affect accuracy of identification, it may have had an effect on identification speed.

Although differences in the absolute values of identification time are reported in the two studies of live television, there is fairly good agreement about the vertical resolution below which a marked decrease in identification speed occurs. In the Elias study, the critical resolution is 6 lines (comparable to the Shurtleff and Owen 12 lines), and in the Shurtleff and Owen study the critical resolution is 10 lines. These data suggest that, if a display situation requires fast symbol identification, then resolutions less than 10 lines are to be avoided. If maximum identification speed is required, then resolutions of 12 or more lines are needed.

Threshold of Identification

Shurtleff, Marsetta, and Showman[12] investigated the effects on the threshold of identification of symbol resolutions of 10, 8, and 6 lines per symbol height.

Standard and revised Leroy alphanumerics (Figure 4) were arranged in groups of 36 (6 rows and 6 columns) with a horizontal spacing between adjacent symbols of 25 percent of symbol height and a vertical spacing between adjacent rows of symbols of 100 percent of symbol height. The symbols were photographed on 35 mm slides and back-lighted by standard, Cool-White, fluorescent lamps. The symbols were picked up by a General Precision television camera (Model PN 5358-6; 945-line) and displayed in the center of a raster of a Conrac 21-inch video monitor (Model CQC; 945-line).

Figure 4. Alphanumerics used by Shurtleff, Marsetta, and Showman. The standard Leroy symbols are at the top and the revised Leroy symbols are at the bottom. (After Shurtleff, Marsetta, and Showman, 1966.)

The subjects were assigned to one of six experimental conditions; one of two lettering fonts and one of three symbol resolutions (10, 8, or 6 lines per symbol height). The measure of legibility was the visual angle subtended by symbol height when the subject was able to achieve 99 percent accuracy of identification.

Table VII shows the results of the study. The visual angles required for 99 percent correct identification are similar for symbol resolutions of 8 and 10 lines. At a resolution of 6 lines, the visual angle required is more than double that for 10 and 8 lines. A statistical analysis shows a significant difference between 6 lines and 8 or 10 lines, but no difference between 10 and 8 lines.

In a second experiment by Shurtleff, Marsetta, and Showman[12], the visual angles required for viewing symbols at the edge of the television raster (to the side of the tube center) were determined. In the first experiment the symbol array was displayed at the center of the raster (middle of the tube face) and there was a question about how the results for the center apply to other positions on the raster. Different results were anticipated because of nonuniformity of focussing over the raster.

The results show that a larger visual size is required for symbols displayed at the edge of the raster than for symbols displayed at the center of the edge of the raster, the visual size needs to be increased 11 percent (1.5 minutes) over that required for symbols displayed at the center of the raster.

One of the few legibility studies from educational uses of television was done by Seibert, Kasten, and Potter[13]. A legibility problem became apparent when television was used as an instructional aid in courses given at Purdue University. The above authors, in an effort to provide legibility criteria for effective use of television in a classroom, conducted a legibility study on live

Table VII

Visual Size in Minutes of Arc Required for 99 Percent Accuracy of Identification, shown for two symbol fonts and three values of vertical resolution. (After Shurtleff, Marsetta, and Showman, 1966.)

	Symbol Resolution		
	10	8	6
Standard Leroy	13. 15	12. 82	35. 97
Revised Leroy	13. 37	15. 09	30. 08

Description of Experimental Conditions:

Symbol Brightness: 20 ft-l

Background Brightness: 2 ft-l

Brightness Contrast: +0. 90

Ambient Illumination: 6 to 8 ft-c

Symbol-Background Relation: L/D

Horizontal Spacing: 25 percent of symbol height

Vertical Spacing: 100 percent of symbol height

Symbol Width: 75 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol height

Symbol Exposure Time: Variable

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 24

Visual Characteristics of Subjects: 20/20 near and far acuity; normal color and phoria

Viewing Distance: 20 to 122 inches

Viewing Angle: 90 degrees estimated for 75, 60, 45, and 30 degrees

television in which they investigated the effects on identification accuracy of symbol size, viewing distance, viewing angle and direction of contrast [dark on light (D/L) vs light on dark (L/D)].

The television equipment consisted of two RCA television cameras (Model TK-11A) and two 24-inch RCA monitors (Model 24-T-6285). The material displayed by the closed-circuit television consisted of 252 black, white, and gray poster-boards on each of which were mounted four Futura symbols (Figure 1). The cards were displayed one at a time on the monitor to subjects who were positioned at various angles and distances of viewing. The subjects were instructed to write the symbols shown in a test booklet. Two television viewing rooms were used with 18 subjects assigned to each room. Each subject was assigned a different viewing location within a room. The locations differed in both distance and angle of viewing.

The results of the study are in Table VIII,[1] and show a decrease in identification accuracy for resolutions below 12 lines and for visual angles smaller than 15 minutes of arc.

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[1]The original presentation of the accuracy of identification scores by Seibert, et al., was for viewing distances and point sizes. It was possible, however, through personal communication with Seibert to obtain sufficient information to allow his data to be replotted in terms of symbol resolutions and visual angles. The replotting of Seibert's data resulted in some discontinuity over symbol resolution and visual angles but enabled his data to be compared more directly with those of other investigators. The accuracy scores of Table VIII have been pooled over all three viewing angles and two directions of contrast. It was not possible to further subdivide the data and plot accuracy against viewing angle and direction of contrast because Seibert had lost the original data.

Table VIII

Accuracy of Identification, in percentage correct for several selected values of visual size and vertical symbol resolution. (After Seibert, Kasten, and Potter, 1959.)

Visual Size	Symbol Resolution			
	20	16	12	8
34	99			
27		99		
21	99			
20			97	56
16		98		
15	98			
12	95	93	97	49
10	80			
9		82	83	26
8	75	60		
7				7
6		47	42	5
5			17	2

Description of Experimental Conditions:

Symbol Brightness: Not stated

Background Brightness: Not stated

Brightness Contrast: Not stated

Ambient Illumination: 25 to 38 ft-c

Symbol-Background Relation: L/D and D/L

Symbol Style: Futura Medium (see Figure 1)

Horizontal Spacing: 50 percent of symbol height*

Symbol Width: 77 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol height

Symbol Exposure Time: 10 seconds

Number of Symbols: 28; I, O, R, 1, 2, 3, 7, and Ø were omitted

Number of Subjects: 36

Visual Characteristics of Subjects: 20/20 near and far acuity

Viewing Distance: 72 to 300 inches

Viewing Angle: 90 to 19 degrees

*Estimated by author of this report.

Conclusions and Recommendations

The study by Seibert et al. shows the minimal acceptable visual size for viewing televised symbols to be between 15 and 12 minutes of arc. The study by Shurtleff, Marsetta, and Showman indicates the minimal angle to be around 13 minutes of arc. The agreement between the two studies is remarkable and increases confidence in the reliability of the findings. The study by Seibert, et al. also shows that increasing symbol resolution up to 20 lines per height will probably not decrease the visual size required for a high accuracy of identification. On the other hand, the study by Shurtleff, Marsetta and Showman showed that symbol resolution can be decreased to as few as 8 lines per symbol height if the visual size is 15 minutes of arc or greater. The data of this study at Purdue conflicted with the data of the other study in that it shows a large loss in legibility for a symbol resolution of 8 lines. However, the reported accuracies in the study at Purdue are for performance pooled over three viewing angles which suggests that 8 lines per height is a marginal resolution and a poor viewing angle can lead to a marked decrease in accuracy at this resolution.

WIDTH OF THE VERTICAL SCAN LINES

In Conclusions and Recommendations, page 13, the effects on legibility of the quality of the interlace of lines composing the two fields of a television raster are discussed. Another feature of the scanning process is the size of the scanning element. The size of the scanning element does not affect the quality of the interlace but does change the ratio of active to inactive element widths within the television raster.

The effects on legibility of changes in the ratio of active to inactive element widths within a television raster were investigated in a study by Botha and Shurtleff[14]. A television raster was simulated by placing a photographic negative in front of Futura style letters (Figure 1). The negative contained alternate opaque and transparent strips; five transparent and five opaque strips were used to cover a symbol. Three different ratios of widths were used to simulate different ratios of inactive to active element widths in a television raster. The ratios of the opaque strip to the width of the transparent strip are 1:2, 1:1, and 2:1. Also, two different scan patterns were simulated by two different placements of the lines over the symbols.

The symbols were shown to subjects one at a time for 0.03 second with a tachistoscope. One group of subjects identified symbols with one placement of the simulated raster on the symbols while a second group identified symbols with a different placement of the raster on the symbol. Both groups identified symbols covered by simulated rasters in each of the three opaque-to-transparent line width ratios.

The results of the study show that identification accuracy and speed of identification decrease as the width of the inactive element increases in the simulated raster. Also, the placement of the raster on the symbol shows a progressively greater effect on legibility as the width of the inactive element increases.

Conclusions and Recommendations

The preceding findings are based on simulated television rasters and have not been verified by use of live television rasters. However, in the absence of any comparable data on live television, the data serve as a tentative guide to optimum raster selection for live displays. It is recommended that when symbol

resolution is as small as 5 to 7 lines per symbol height, the ratio of the widths of inactive to active elements be no greater than 1:1. Ratios greater than this probably increases errors of identification as well as produces a raster in which adequate legibility could be attained only by careful registration of the scan lines on the symbol.

ANGULAR SCAN LINE ORIENTATION

In most cases, alphanumeric information is displayed on television with the raster lines oriented parallel to the base of the symbols. There is a question, however, as to whether the conventional orientation of the scan lines or some other orientation might produce more legible symbols. The idea that line scan orientation might affect legibility is based on the fact that changes in the orientation of the scan lines lead to associated changes in the geometry of symbols displayed. Also, in some applications, such as Air Traffic Control, it is often inconvenient to orient the scan lines and symbols in the same way, and it is important to determine if legibility of symbols is affected by different orientations of the scan lines.

Shurtleff, Botha, and Young[15] investigated the effects on legibility of three different orientations of idealized television scan lines. In one case the scan lines were parallel to the base of the symbols; in a second case, they were at an angle of 45 degrees with the base of the symbols; and, in a third case, they were oriented perpendicular to the base of the symbol.

The apparatus, symbols, method of displaying the simulated television raster, exposure times, and symbol resolutions are the same as those described in the study[8] on page 5.

A mixed experimental design was used in which each subject was assigned to only one condition of scan line orientation, but to all conditions of symbol resolution and exposure time. Four subjects were assigned to each scan line orientation.

The results show that scan line orientation had no statistically significant effect on either identification accuracy or speed. Identification accuracy and speed were slightly better when the scan lines were oriented 45 degrees to the base of the symbols than in either of the other two orientations.

Conclusion

There is no evidence at this time that angular scan line orientation is a significant factor in symbol legibility.

VIDEO BANDWIDTH

An unpublished study by Seibert[16], [2] investigated the effects on legibility of 5 bandwidths of 4 mc, 2 mc, 1.5 mc, 1.0 mc, and 750 kc. The study was similar to that of Seibert, et al.[13] with respect to the symbols used, subject's seating arrangement, and other factors investigated.

The television equipment included two Marconi Mark 4 (4-1/2-inch I-O) cameras and two Conrac CMB 21-inch monitors.

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[2] Received as personal communication.

Ninety subjects were used in the study, but they were not screened for visual defects. The subjects were assigned randomly to one of the five bandwidth conditions. The 18 subjects in a group were each assigned to 1 of 18 viewing locations. The 18 locations were in 3 different rooms with 6 viewing positions per room. Within a room, three viewing positions were in a line directly in front of the monitor while the remaining three viewing positions were in a line 30 degrees from the first. Viewing positions were located at 9, 14, and 19 ft from the monitor for each line (angle) of viewing.

A group of four Futura symbols (Figure 1) was shown for 10 seconds, and the subjects were asked to identify the symbols and to write them in a test booklet. Other details of the experiment were similar to those described in Table VIII.

The results shown in Table IX suggest a somewhat complicated relation among the three factors, video bandwidth, vertical symbol resolution, and visual size. In general, there is little difference between bandwidths of 4 and 2 mc at any value of symbol resolution of visual size. The results shown in the remainder of the table are somewhat confusing. In general, it may be said that decreases in bandwidth below 2 mc have a progressively greater effect as vertical symbol resolution and visual size decrease. For example, at a symbol resolution of 18 lines and a visual size of 15 minutes of arc, there is little decrease in identification accuracy until the bandwidth decreases to 750 kc. However, at a symbol resolution of 6 lines and a visual size of 6 minutes of arc, there is a progressive decrease in identification accuracy for each decrease in video bandwidth.

Table IX

Accuracy of Identification, in percentage correct for four values of vertical symbol resolution, for five values of video bandwidth, and for selected values of visual size. (After Seibert, undated.)

Lines Per Symbol Height	Vertical Visual Size	Horizontal Resolution in Bandwidth				
		4. 0 mc	2. 0 mc	1. 5 mc	1. 0 mc	750 kc
18	15	99. 8	99. 8	99. 1	99. 3	92. 1
	10	95. 1	95. 7	97. 3	97. 0	84. 1
	7	95. 1	94. 4	98. 1	81. 5	60. 1
14	12	98. 8	98. 9	97. 5	97. 2	83. 4
	8	85. 8	91. 0	88. 7	86. 8	68. 6
	6	83. 0	83. 4	90. 2	62. 4	32. 5
10	9	97. 9	97. 2	90. 5	92. 6	58. 8
	6	71. 1	83. 5	68. 7	58. 8	44. 6
	5	56. 6	68. 0	63. 5	34. 5	13. 5
6	6	75. 5	57. 8	36. 4	33. 1	18. 2
	4	23. 1	34. 2	16. 6	10. 1	8. 0
	3	6. 6	17. 0	10. 1	4. 9	2. 0
Average (all sizes and distances)		74. 0	76. 8	71. 4	63. 1	47. 2

Description of Experimental Conditions:

Symbol Brightness: Not stated

Background Brightness: Not stated

Brightness Contrast: Not stated

Ambient Illumination: Not stated

Symbol-Background Relation: L/D and D/L

Symbol Style: Futura Medium (see Figure 1)

Horizontal Spacing: 50 percent of symbol height*

Symbol Width: 77 percent of symbol height

Symbol Stroke-Width: 16 percent of symbol height

Symbol Exposure Time: 10 seconds

Number of Symbols: 28; i, o, r, 1, 2, 3, 7, and Ø were omitted

Number of Subjects: 90

Visual Characteristics of Subjects: Not Stated

Viewing Distance: 9, 14, and 19 ft

Viewing Angle: 0 and 30 degrees

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* Estimated by author of this report.

Conclusions and Recommendation

The data fail to show how identification accuracy is affected by video bandwidths greater than 4 mc. In the so-called "high-resolution" television system, bandwidth may be as great as 20 mc. It is possible that bandwidths greater than 4 mc will lead to improved accuracy for the smaller values of vertical symbol resolution and visual sizes used by Seibert. More will be said of the possible effects on legibility of increased video bandwidth in the section to follow on the quality of television equipment.

The data clearly indicate that, for the practical applications, bandwidths less than 2 mc should not be used.

QUALITY OF TELEVISION EQUIPMENT

It is well known that closed-circuit television equipment, like most other kinds of equipment, varies greatly in quality. The price range of television equipment attests to quality differences ranging from several hundreds of dollars to several thousands of dollars. From an economical point of view, it is of some interest to know if legibility is significantly improved by the use of good quality television equipment. Furthermore, it is of interest to determine if findings with one kind of television equipment can be generalized to other television equipment.

Accuracy of Identification

A study by Shurtleff and Owen[17], compared the minimum symbol resolution required for symbols displayed on an inexpensive, commercial, 525-line television system with that required for symbols displayed on a good quality General Precision 945-line television system. Accuracy of identification of standard Leroy symbols (Figure 4) was compared for the two television systems at 6, 8, 10, and 12 lines per symbol height.

The 525-line system included a Fairchild TC-100 television camera and a Miratel 14-inch video monitor. The 945-line system included a General Precision camera (PN 5358-6) and a Conrac 21-inch video monitor.

Leroy symbols were shown one at a time in the center of the video monitor raster. The subject was equipment with a hand-operated switch to start the exposure of a symbol, and a microphone to terminate the exposure upon verbal identification. Four subjects identified symbols resolved by 6, 8, 10, or 12 lines per symbol height on the 525-line system, and four subjects identified symbols at these same resolutions on the 945-line system.

The results of the study are shown in Table X where it is noted that accuracy of identification is similar for both systems at resolutions of 12, 10 and 8 lines, but at 6 lines accuracy is better for the 945-line system than for the 525-line system.

Conclusions and Recommendations

The quality of television equipment apparently has little effect on accuracy of identification when vertical symbol resolution has 8 lines or more. Some advantage in the use of good quality equipment is noted for symbol resolutions less than 8 lines. Since accuracy is no better at 8 lines for the good quality equipment than for the low-cost television equipment, the recommendation of a minimum resolution of 10 lines applies as well to good quality television as it does to inexpensive television equipment These data also suggest, when considered with those of Seibert[13], that increases in video bandwidth from 4 mc (Seibert's study) to 20 mc (the bandwidth of the 945-line system) increases accuracy of identification for small values of vertical symbol resolution and small visual sizes. However, the amount of improvement potentially attributable to increased bandwidth is not sufficiently great to change recommendations

Table X

Accuracy of Identification, in percentage correct for good-quality (945-line) and low-cost (525-line) television equipment at four values of vertical symbol resolution. (After Shurtleff and Owen, 1966.)

Television System	Lines Per Symbol Height			
	12	10	8	6
945-line	99.0	96.4	92.8	89.0
525-line	97.2	96.5	91.4	77.5

Description of Experimental Conditions:

Symbol Brightness: 20 ft-l

Background Brightness: 2 ft-l

Brightness Contrast: +0.90

Ambient Illumination: Not stated

Symbol-Background Relation: L/D

Symbol Style: Leroy (see Figure 2)

Horizontal Spacing: Not relevant

Symbol Width: 75 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol height

Visual Size: 11 minutes of arc

Symbol Exposure Time: Variable

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 8

Visual Characteristics of Subjects: 20/20 near and far acuity; normal color and phoria

Viewing Distance: 36 to 64 inches

Viewing Angle: 90 degrees

of vertical symbol resolutions (minimum of 10 lines) and visual size (minimum of 15 to 16 minutes of arc) for television equipment operating on lower bandwidths.

Rate and Speed of Symbol Identification

The study discussed in the preceding paragraphs also recorded speed of identification. These data are in Table XI. Identification speeds for the two television systems were similar for symbol resolutions of 12, 10, and 8 lines but at 6 lines, identification speed was better for the 945-line system than for the 525-line system.

Conclusions and Recommendations

Because of the similarities in findings for speed and accuracy scores, the recommendations given in the preceding conclusions and recommendations for accuracy of identification apply as well to speed of identification.

SYMBOL STYLE

It is noted in Angular Scan Orientation, page 27, that the raster-scan method of construction produces changes in the geometry of symbols. Is it possible then, because of the raster-scan method of construction, that a symbol font can be derived that is uniquely suitable for television displays? Rowland and Cornog of the Courtney Company thought so, and they designed a set of alphanumeric symbols (Figure 2) especially for television displays used in an Air Traffic Control system (SPANRAD). Shurtleff and Owen[9] points out that the subjective method used to select symbols of the new design does not guarantee that operators in the SPANRAD system are able to identify symbols in the new font any more accurately or rapidly than those of a more conventional design. Therefore, a test of the legibility of the Courtney symbols was performed in the following described study.

Table XI

Speed of Identification, in seconds for good quality (945-line) and low cost (525-line) television equipment at four values of vertical symbol resolution. (After Shurtleff and Owen, 1966.)

Television System	Lines Per Symbol Height			
	12	10	8	6
945-line	0.47	0.50	0.66	0.79
525-line	0.49	0.54	0.70	1.08

Description of Experimental Conditions:

Symbol Brightness: 20 ft-1

Background Brightness: 2 ft-1

Brightness Contrast: +0.90

Ambient Illumination: Not stated

Symbol-Background Relation: L/D

Symbol Style: Leroy (see Figure 2)

Horizontal Spacing: Not relevant

Symbol Width: 75 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol height

Visual Size: 11 minutes of arc

Symbol Exposure Time: Variable

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 8

Visual Characteristics of Subjects: 20/20 near and far acuity; normal color and phoria

Viewing Distance: 36 to 64 inches

Viewing Angle: 90 degrees

Accuracy of Identification

Shurtleff and Owen[9] compared the legibility of Courtney symbols with those of Leroy, a conventional letter set. The two fonts were compared at symbol resolutions of 12, 10, 8, and 6 lines. Details of the experiment are given on page 5.

The results of the study, shown in Table II, indicate that, with little practice (Part I), the Courtney symbols are not superior to those of a conventional design and are identified less accurately than the Leroy at each value of symbol resolution. With practice (Part II), the accuracy of identification is similar for the two fonts except at a resolution of 6 lines per symbol height, where Courtney was superior. There are no statistically significant differences between fonts for either Part I or Part II.

Conclusions and Recommendations

The use of objective techniques shows the specially designed symbols are no better than those of conventional design. Since no advantage is derived from the use of the Courtney symbols, the Leroy symbols are to be preferred, and are recommended, because of their familiarity, ease of construction, and greater availability. These findings are not to be taken to imply that it is not possible to design a better set of symbols for television use. The findings do show that the ultimate test of the value of a new symbol font is one which shows that the operator's identification of new symbols is better than his identification of symbols in a more conventional design.

Rate and Speed of Symbol Identification

The study of Shurtleff and Owen[9] described in the preceding paragraphs also shows the speed with which subjects are able to identify Courtney and Leroy symbols at resolutions of 12, 10, 8, and 6 lines. These data are in Table V where it is noted that subjects with little practice (Part I) took more

time to identify Courtney symbols than Leroy symbols at each value of resolution. After practice (Part II), the speed of identification scores are similar for the two fonts. There are no statistically significant differences between fonts for either Part I or Part II.

Conclusions and Recommendations

Since the findings for speed scores are similar to those for accuracy of identification scores, the recommendations outlined also apply here.

Threshold of Identification

The study described in Threshold of Identification, page 19, investigated the effects on visual size of standard Leroy symbols and a revised set of Leroy symbols (see Figure 4 and Table VII). Most of the changes in symbols shown in Figure 4 did not improve the threshold of identification, and in some cases, e.g., the "K" and "one", lead to a decrease in performance.

Conclusion and Recommendation

Of the changes evaluated, only the revisions of the "H" and "B" are successful and it is recommended therefore that only these two revisions be incorporated in the standard Leroy font for use on television displays.

SYMBOL STROKE-WIDTH

Accuracy of Identification

The study by Botha and Shurtleff[8] evaluated stroke-widths of 17 and 28 percent of symbol height. The results of the study are in Table I. Stroke-width did not affect accuracy for a symbol resolution of 11 lines and an exposure of 0.03 second. At the same exposure time, accuracy was better for the wider

width when symbol resolution was 5 lines. At an exposure of 0.003 second, accuracy was better for the wider width than the narrower width for each value of symbol resolution.

Conclusions

The data on stroke-widths are incomplete and no specific recommendations are possible for television displays. These data do suggest the use of a wide stroke-width for small values of symbol resolution.

Rate and Speed of Symbol Identification

The speed of identification scores for stroke-widths of 17 and 28 percent of height are in Table IV. These data are from the study by Botha and Shurtleff[2]. At an exposure of 0.03 second, the value of stroke-width does not affect speed of identification. When exposure time is decreased to 0.003 second, speed of identification tends to be better for the wide stroke-width for both values of symbol resolution.

Conclusions

The speed data, like the accuracy data, for stroke-width are incomplete and no specific recommendations are offered for television displays.

SYMBOL EXPOSURE TIME

The effects of exposure time of 0.03 and 0.003 second on accuracy and speed of identification are shown in Tables I and IV. These data are from a study by Botha and Shurtleff[8]. Accuracy and speed of identification are better for both symbol resolutions at 0.03 second than at 0.003 second.

Conclusions

More data are needed on exposure time before specific recommendations are possible. Furthermore, the data apply only when the subject knows in advance where the symbol is to appear. Obviously, if he is required to search for a symbol (does not know in advance where it is to appear) much longer times will be required than those investigated in the above study.

VIEWING ANGLE

Threshold of Identification

The study by Shurtleff, Marsetta, and Showman[12] determined visual sizes required for viewing television displays for different angles of viewing. The data of the study are shown in Table XII. The visual sizes for the 90 degree viewing angle were determined experimentally, and represent the sizes required for 99 percent accuracy of identification for symbol resolutions of 8 and 10 lines (top row of Table XII at each resolution). The visual sizes for angles of viewing were for symbols displayed over the entire television raster. For the center portion of a television raster, the data of Table VII was used instead of the data of Table XII in determining visual sizes required for different angles of viewing. The angles shown in Table VII were for a 90 degree viewing angle. Appropriate sizes for other angles of viewing were estimated by Reinwald's formula.

Conclusions and Recommendations

It is recommended the visual sizes given in Table XII be used as design guides for layout of the viewing area for television displays. The bottom row of the table for each resolution should be used since it corrects, to some extent, the potential variations in equipment and subjects. Also, Seibert's data (Table VIII) suggest that it may be possible to extend the recommended visual

Table XII

Visual Sizes, in minutes of arc for 99 percent accuracy of identification for two values of vertical symbol resolution and five viewing angles. Shown at each resolution are visual sizes corrected for differences among subjects and variation in television equipment. (After Shurtleff, Marsetta, and Showman, 1966.)

Symbol Resolution		Viewing Angle in Degrees				
		90	75	60	45	30
10	uncorrected	17	20	24	32	55
	corrected	20	24	28	36	63
8	uncorrected	21	24	28	38	-
	corrected	24	28	32	44	-

Description of Experimental Conditions:

Symbol Brightness: 20 ft-l

Background Brightness: 2 ft-l

Brightness Contrast: +0.90

Ambient Illumination: 6 to 8 ft-c

Symbol-Background Relation: L/D

Horizontal Spacing: 25 percent of symbol height

Vertical Spacing: 100 percent of symbol height

Symbol Width: 75 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol height

Symbol Exposure Time: Variable

Number of Symbols: 26 Letters; 10 Numerals

Number of Subjects: 24

Visual Characteristics of Subjects: 20/20 near and far acuity; normal color and phoria

Viewing Distance: 20 to 122 inches

Viewing Angle: 90 degrees estimated for 75, 60, 45, and 30 degrees

sizes to symbol resolutions of approximately 20 lines per symbol height, since visual size does not appear to decrease with increased symbol resolution. One might expect visual size required for 99 percent accuracy of identification to decrease with increases in symbol resolution. The reason for this is that it is possible with solid stroke symbols of good quality to reduce the visual size to 9 to 10 minutes of arc and still maintain a 99 percent accuracy of symbol identification. A vertical resolution of 20 lines should closely approximate the construction of nontelevised, solid stroke, symbols. It seems, therefore, that the minimal visual size is limited by other characteristics of television besides vertical resolution (possibly phosphor resolution).

DIRECTION OF CONTRAST

In a study by Kelly[18], the effects on legibility of direction of contrast and intensity of ambient illumination were investigated. The object of the study was to provide data for use in the design of television displays viewed in a wide degree of ambient illumination, for example, television displays in airplane cockpits.

A closed-circuit television system was used which included a Kintel camera (Model 1988-C) and DRM, 14-inch, video monitor. A slide projector displayed groups of letters and numerals which were picked up by the camera and shown to the subjects at the center part of the monitor screen.

Thirty-five mm slides containing 20 Futura symbols each (Figure 5) were used; each slide contained 14 letters and 6 numerals. Nine slides were

ABCDEFGHIJKLMN 1 2 3 4 5 6 7 8 9 0

Figure 5. Symbols Similar in Style to Those Used by Kelly.

prepared with L/D symbols and nine slides with D/L symbols. The symbols had a resolution of 5 lines per symbol height.[3]

Three levels of ambient illumination were used; 0.03, 186.4 and 638.4 ft-c. The illumination was provided by photo floodlights which shone directly on the screen of the television monitor. Brightnesses of light and dark areas of the monitor screen were measured by a Macbeth Illuminometer under each of the three ambient light conditions, and were, for light areas 16.2, 31.9, 56.8 ft-l, and for dark areas, 5.7, 16.1, and 32.0 ft-l. Each subject identified symbols for all combinations of the experimental conditions, two directions of contrast and three levels of illumination.

The results of the study (Table XIII) showed a progressive loss of identification accuracy as illumination increases for both L/D and D/L. L/D symbols were recognized more accurately under the low condition, while D/L symbols were recognized more accurately under the medium and high conditions.

In the two studies by Seibert[13] [16] accuracy of identification was measured for the two directions of contrast. One study[13] showed D/L symbols to be more accurately identified than L/D symbols while the second study showed the reverse finding; L/D symbols were identified more accurately than D/L symbols. In both studies the differences due to direction of contrast were

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[3] It is not indicated in the study how many actual television scan lines compose a symbol resolution of 5 lines. The best guess is that each line actually comprised 2 linear scans that were scans that were either paired or superimposed to some degree so that they were visually indistinguishable. This problem is discussed on pages 9 and 13.

Table XIII

Accuracy of Identification, in percentage correct for the two directions of contrast and three values of ambient illumination. (After Kelley)

Direction of Contrast	Ambient Illumination		
	Low	Medium	High
D/L	88	81	73
L/D	93	77	66

Description of Experimental Conditions:

Symbol Brightness: L/D: 16.2, 31.9, 56.8; D/L: 5.7, 16.1, 32.0 ft-l

Background Brightness: L/D: 5.7, 16.1, 32.0; D/L: 16.2, 31.9, 56.8 ft-l

Brightness Contrast: ±0.65, ±0.49, ±0.44 ft-l

Ambient Illumination: 0.026, 186.4, 638.4 ft-c

Symbol Style: Futura Demibold (see Figure 5)

Horizontal Spacing: Not stated

Vertical Spacing: Not stated

Symbol Width: 84 percent of symbol height

Symbol Stroke-Width: 17 percent of symbol Height *

Visual Size: 20 minutes of arc *

Symbol Exposure Time: 15 seconds

Number of Symbols: 20 — mixture of 14 letters and 6 numerals

Number of Subjects: 12

Visual Characteristics of Subjects: 20/20 binocular acuity; normal color

Viewing Distance: Not stated; assume 20 to 28 inches *

Viewing Angle: 90 degrees

* Estimated by author of this report.

not large. In one study[13] the average accuracy of identification was 70.9 percent for D/L symbols and 66.3 percent for L/D symbols. The biggest differences between directions of contrast occurred at a symbol resolution of 8 lines. Minor differences due to direction of contrast were noted for symbol resolutions of 12, 16, and 20 lines. In a second study[16] even smaller differences in accuracy of identification were reported for the two directions of contrasts.

Conclusions and Recomendations.

The data reported so far are not conclusive about the relative legibilities of D/L and L/D symbols. The evidence suggests that direction of contrast does not affect accuracy to any great degree unless some other factor affecting legibility is marginal; for example, a small value of symbol resolution or an extremely high or low ambient. In cases where other factors were at marginal values, D/L symbols were in most cases superior in legibility to L/D symbols.

Therefore, either D/L or L/D symbols may be used interchangeably in most television display situations. The superior legibility of D/L symbols is found only for display situations producing error rates which are too high for system applications. That is, situations in which D/L symbols might be preferred are probably not acceptable for system applications because of excessively high error rates.

SURROUND BRIGHTNESS

The effects on legibility of surround brightness were discussed on pages 8 and 9 of Part I[2] of this report series. There is little information from the television literature which suggests any changes in conclusions and recommendations previously outlined. While there have been a few studies of surround brightness appropriate for use with television displays, they have

not been concerned with the effects of surround brightness on the legibility of television displays, but with the effects of surround brightness on the "visual comfort" of the viewer.

For example, Nixon[5] had several observers view a picture on a television screen and adjust the luminance of the surround until they found the brightness most satisfactory for viewing comfort. The observations were made for several values of peak luminance (expressed also as mean screen luminance) from 10 to 80 ft-l and for three surround areas. The television display subtended an angle of 9° vertically and 12° horizontally at the eye; the smallest surround area subtended an angle of 12° vertically and 14° horizontally; the medium surround area, 17° vertically and 23° horizontally; the large surround area, 23° vertically and 32° horizontally. These data are shown in Figure 6, where surround brightness required for visual comfort are plotted against peak and mean screen luminance of the television screen. Most observers preferred the two largest surrounds over the smallest.

Conclusions and Recommendations

There is insufficient evidence about the effects of surround illumination on legibility to warrant any recommendation of brightness values for television displays. While Nixon's data shows brightness values required for expression of visual comfort there is no way to relate an observer's judgment of visual comfort to his performance in identifying symbols at those same brightness values. The little data that is known about surround brightness (pages 8 and 9 Part I of this series of reports[2]) suggests that the surround brightness reported by Nixon for visual comfort may be too dim for maximum symbol legibility.

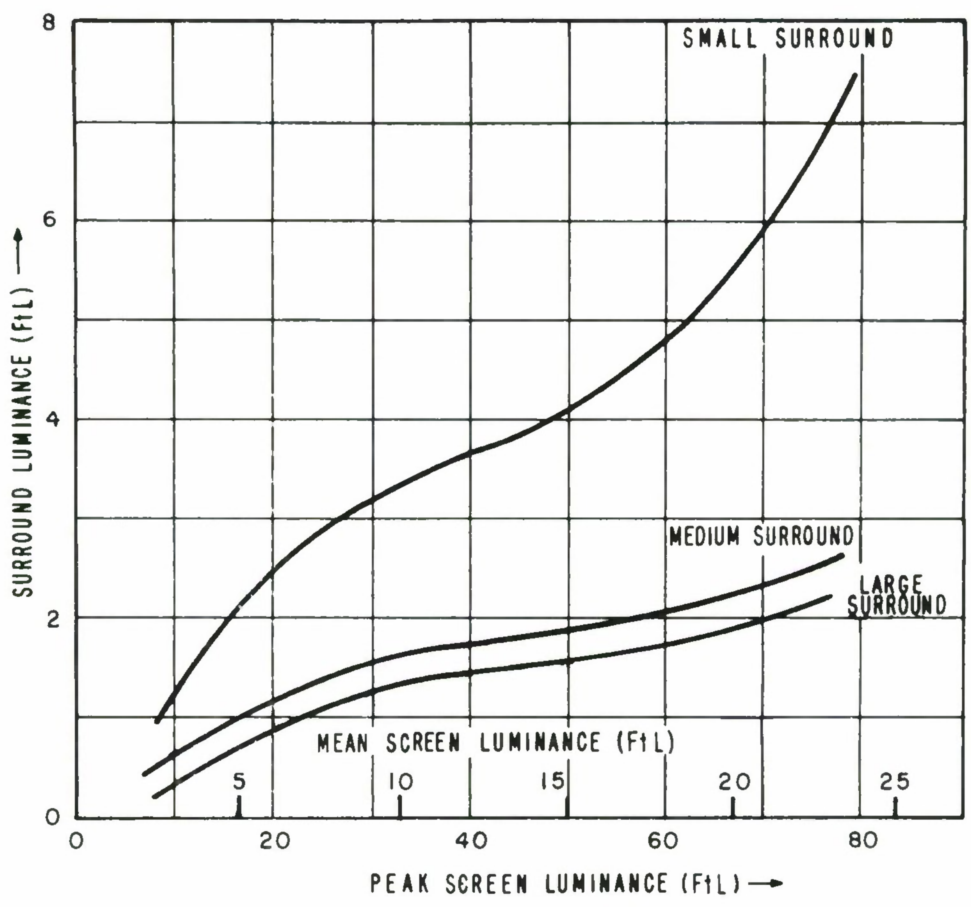

Figure 6. Mean Value of Surround Brightness Preferred by Viewers of Broadcast Television. Plotted for three surround areas at each of five values of peak screen luminance. (After Nixon, 1965.)

SECTION IV

SUMMARY OF THE LEGIBILITY OF TELEVISED WORDS

The major part of research on television legibility is concerned with the identification of alphanumeric symbols. In studies of alphanumerics, like those summarized in Section III, the symbols are usually presented one at a time (or, in some cases, in groups), but in all cases, the identification is made without benefit of contextual clues. The symbols appear with equal frequency and in some unpredictable sequence. The situation is quite different, however, when these same symbols are used to construct messages such as words or text. When alphanumerics are used in words, contextual clues may be expected to assist letter identification; the reason being the redundancy among letters in familiar words may make the word readable even though each letter, when seen alone and out of context, is less legible or in some cases even illegible.

Because of the differences in availability of contextual clues, the findings for single symbols cannot be generalized to words, and conversely, the findings for words cannot be applied to single symbols. It is necessary, therefore, as done in the studies reported here, to determine the legibility requirements for televised words.

VERTICAL RESOLUTION

Accuracy of Identification

Kosmider[19] determined viewers' ability to read five-letter words with symbol resolutions of 5, 7, and 10 lines per symbol height and for nontelevised words composed of solid-stroke letters. The televised words were shown by

a 525-line, closed-circuit system consisting of a Fairchild camera (Model TC-100) and a Miratel, 14-inch, video monitor.

One hundred common, five-letter words were used with a frequency of usage of 30 to 49 per 1,000,000 words in the English language[20]. The words were composed of capital letters (Figure 7). They were projected onto the screen of a modified motion analyzer and were picked up by the television camera and displayed in the center part of the monitor screen.

Twelve subjects with 20/20 acuity, normal color vision, and no marked phoria were used. Each of the 12 subjects was shown the words in three conditions, solid-strokes and television resolutions of 10 and 7 lines per word height. Also, 6 of the 12 subjects were shown words composed of 5 lines per symbol height. A subject was shown 100 words for each condition of viewing. The subject presented the word to himself by depressing a finger-operated button, and his vocal identification of the word activated a voice-operated relay shutting off the display. A constant visual size of 16 minutes of arc (symbol height) was maintained for the different television resolutions by appropriate adjustments of the distance from which the subject viewed the words.

The results showed that accuracy was approximately 99 percent for words composed of solid-stroke letters and for words composed of 10 or 7 lines per word height. Accuracy dropped off slightly to approximately 97 percent for words composed of 5 lines per height.

Conclusion and Recommendation

Kosmider's data show that it is possible to use as few as 7 lines per word height and still retain a high accuracy of word identification. Resolutions less than 7 lines per height should be avoided since accuracy decreased for resolutions less than 7 lines.

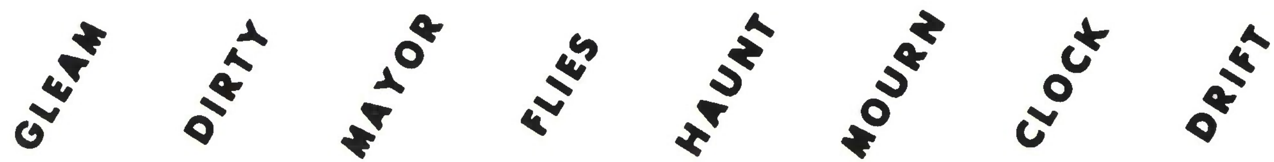

Figure 7. Some Examples of Words Used in Kosmider Study
(After Kosmider, 1965.)

Rate and Speed of Word Identification

In the study[19] described in the preceding paragraphs, the speed with which subjects were able to identify words was also reported. The results are shown in Table XIV. Identification speed was slower for all televised words than for words composed of solid-stroke letters. Also, there was a systematic decrease in speed of identification as word resolution decreased from 10 to 5 lines per height.

Conclusions and Recommendations

If maximum speed of word identification is important, then symbol resolution should certainly be no less than 10 lines per height. In fact, the data suggest that maximum speed of identification will be attained at some value of resolution greater than 10 lines. This optimum value of resolution is not known at this time.

QUALITY OF TELEVISION EQUIPMENT

In a second study by Kosmider, Young, and Kinney[21], the legibility of words on a good quality television system was determined. The present study was identical to that described in Vertical Resolution, page 47, the sole exception that a good quality, 945-line television system consisting of a General Precision camera (Model P/N 5358-6) and a Conrac, 21-inch, video monitor (Model CQC) was used in place of the low-cost equipment. The results showed both accuracy and speed of word identification to be similar to that for the low-cost equipment and, therefore, the results described in the paragraph on page 48 and in Table XIV apply to the good quality television equipment as well.

Table XIV.

Speed of Identification, in seconds for three values of vertical symbol resolution and for solid-stroke symbols. (After Kosmider.)

Lines Per Symbol Height			
Solid	10	7	5
0.35	0.45	0.48	0.65

Description of Experimental Conditions:

Symbol Brightness: 20 ft-l

Background Brightness: 2 ft-l

Brightness Contrast: +0.90

Ambient Illumination: 5 ft-c

Symbol-Background Relation: L/D

Symbol Style: Headliner (see Figure 7)

Horizontal Spacing: 32 percent of symbol height

Symbol Width: 72 percent of symbol height

Symbol Stroke-Width: 25 percent of symbol height

Visual Size: 16 minutes of arc

Symbol Exposure Time: Not relevant

Number of Symbols: 100

Number of Subjects: 12

Visual Characteristics of Subjects: 20/20 near and far acuity; normal color and phoria

Viewing Distance: varied from 20 to 60 inches

Viewing Angle: 90 degrees

Conclusions and Recommendations

Since the findings were similar for both good quality and low-cost television systems, the conclusions and recommendations outlined on page 48 apply here.

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The literature on the legibility of numerals, capital letters, and records on television displays, dating from the late 1940s to the present is evaluated. Selected studies of such factors as vertical resolution, video bandwidth, and direction of scanning are reviewed in detail. Conclusions are drawn, and recommendations are made for display design and application.

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